Magnetoencephalography and surgery for lesional extrahippocampal epilepsy in children

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1 Introduction

Patients with intractable epilepsy due to lesions may undergo surgical treatment of both the lesion and the seizures. The surgical plan which lesion may be completely resected and which seizures has to be controlled remains for the team of epilepsy surgery, including neurosurgeon, neurologist, and neuroradiologist. In these cases, the extent of surgical resection is sometimes guided by spikes recorded on intraoperative electrocorticography (ECoG).

Relationships between postresection spikes and seizure outcome has been reported that tendency of residual extramarginal spikes correlate to the seizure recurrence (1, 2). Whether spikes recorded on the intraoperative ECoG imply active epileptogenesis has been uncertain.

Recent clinical application of MEG studies (3-7) have correlated the results of MEG epileptic spike localizations with conventional noninvasive and invasive localizing modalities in patients with refractory seizures who are candidates for epilepsy surgery. These studies have concluded that MEG, a noninvasive technique, may be useful for localizing the epileptogenic zone.

In this study, we sought to determine whether the spatial extent of MEG spike sources in pediatric patients with extrahippocampal lesional epilepsy predicts surgical outcome. We investigate the relations among the location of interictal MEG spike sources, lesion on MRI, surgical procedures, ECoG results, pathological substrates, and follow-up seizure outcome.

2 Methods

We studied MEG in 13 children with extrahippocampal lesional epilepsy including 5 patients with post-operative recurrent seizures. MSF were divided into four different groups; A) within the lesion; B) at the margin; C) on the remote area; D) on the contralateral homotopic region. MEG spike sources and somatosensory evoked magnetic fields were compared with the results of intraoperative electrocorticography (ECoG) using intraoperative navigating system, and invasive intracranial video electroencephalography (IVEEG) using subdural electrodes. Six patients underwent intraoperative somatosensory evoked potential (SEP) and cortical stimulation to identify sensory-motor cortex. Three required IVEEG for the identification of epileptic region within the eloquent cortex. Seizure and neurological outcomes were reviewed.

MR images were obtained at our facility in a multisequence sagittal, axial, and coronal volume-acquisition study with T1-weighted thin-slice MRI that used 1.5-tesla Signa MRI (Siemens, Germany). Gadolinium was injected into patients with suspected tumors.

Before the MEG study, the patients were admitted to the epilepsy monitoring unit where they were monitored for up to 96 hours of a 5-day admission. The international 10–20 scalp electrode- placement system was used; closely spaced electrodes based on the 10–10 system were placed to cover the suspected epileptic regions. All electrodes were affixed to the scalp with collodion. A single reference electrode was used, such as Oz or Pz' (located 1 cm behind Pz). A black-and-white closed-circuit cable- television monitoring system was used, with infrared illumination at night. Split-screen and time-locked EEG was used to review the clinical behavior of seizures (BMSI 4000 and 5000, Nicolet Biomedical Inc., Madison, WI). EEG data were digitized at a sampling rate of 200 samples per second per channel. Digitized EEG segments showing epileptic activity were selected by automatic seizure detection, patient-alarm button, or automatic spike detection and stored.

MEG studies were performed at Scripps Clinic and Research Foundation in San Diego, CA, using a Magnus II (74-channel) or whole-head Magnus 2500 WH (148-channel) in six children (4D Neuroimaging, San Diego, CA). Biomagnetometer probes were housed in a magnetically shielded room (3 x 4 x 2.5

m). MEG methods and analysis have been described in previous reports (3). In three adolescents, somatosensoryevoked response (SEF) was measured by using tactile stimulation of the thumb (D1), index finger (D2), little finger (D5), and lower lip(LL) (8). We analyzed MEG spike sources around the lesion, for distribution of cubical surface around the lesion. The number of MEG spikes were plotted onto the each plane of the cubic to define the asymmetry.

Subdural grids with up to 128 contacts were constructed based on the interictal and ictal EEG results, the interictal MEG spike sources and somatosensory-evoked fields, clinical signs and symptoms, using 128 thin-slice (1.5–2 mm) T1 images (ISG viewing wand system, ISG Technologies, Mississauga ON). Split-screen and time-locked video-EEG was used to review the clinical behavior of seizures (BMSI 5000). The digitized EEG data (200 samples/sec/channel) were selected by means of alarm button triggers, automatic seizure and spike detection, and stored for review. A voltage topographic mapping technique (Insight, Persist Development, Prescott, AZ) was used to visualize the interictal and ictal spike fields, and propagation on the actual picture of brain surface.

A 4 X 5 surface electrode array (Ad-Tech, Racine, WI) was used for intraoperative electrocorticography (ECoG) to localize interictal epileptiform discharges on the cortex. A viewing wand (ISG Viewing Wand System, ISG, Mississauga, ON, Canada) was used to navigate the lesion and to point the epileptic zone based on the MEG-spike field.

3 Results

MSF was co-localized within the lesion in 5 (A), including 2 with mirror foci (D). Marginal MSF was found in 7 (B), including 3 with mirror foci (D). In 1, MSF was located laterally in the second next gyrus to the left mesial frontal tumor (C). Surgical procedure consisted of lesionectomy with multiple subpial transection (MST) in 4, lesionectomy with marginal cortical excision in 5, and lesionectomy alone in 4. MSF was correlated to the either interictal ECoG or IVEEG epileptic zone in 12. One patient underwent right anterior temporal lobectomy for cortical dysplasia without ECoG. Pathological findings were reported cortical dysplasia in 6, low-grade glioma in 5, gliosis and porencephalic cyst one each. Twelve patients have been seizure free with follow-up period ranged 6 months to 4 years (mean 3.2 years). In 5 patients who suffered residual lesion and recurrent seizure after the last surgery, 4 patients have been seizure free after lesionectomy and MST. One of the 5 patients with diffuse cortical dysplasia had residual nocturnal generalized tonic clonic seizures after the second extensive right temporal cortical excision.

4 Discussion

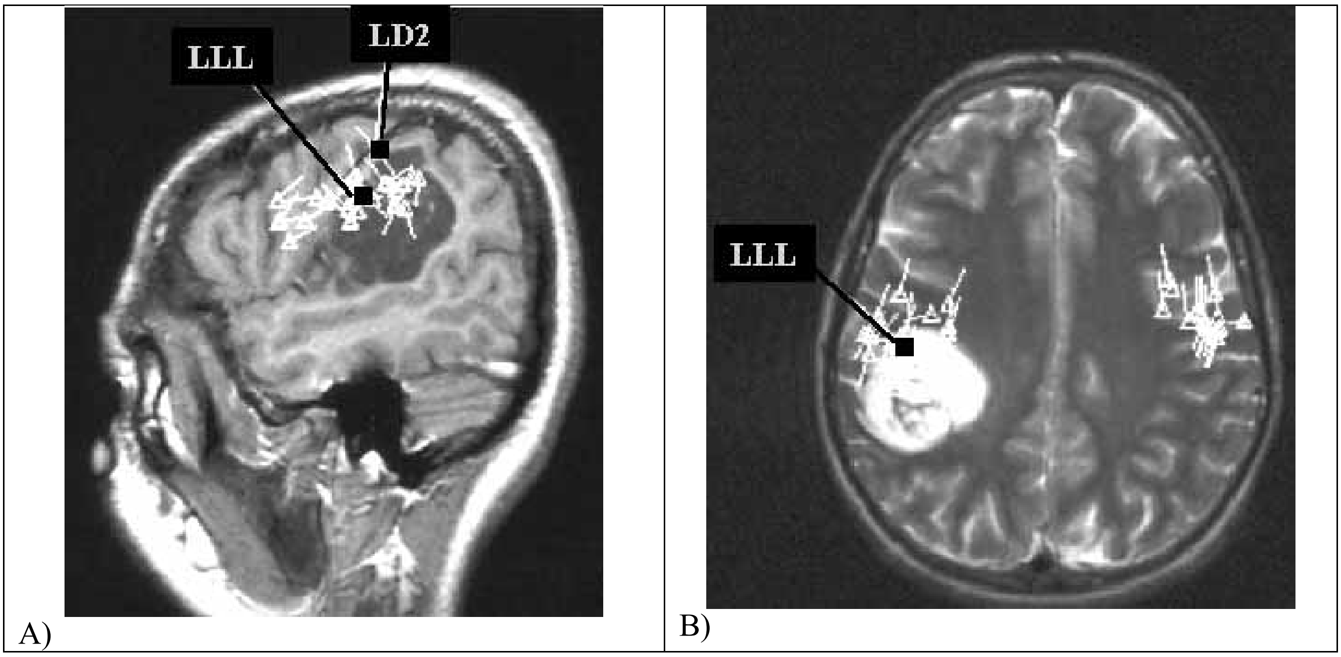
For the surgical treatment of seizure disorders secondary to a lesion, the epileptogenic lesion, which causally relates the epilepsy, and the epileptogenic zone, which generates the clinical seizures, have to be removed totally or disconnected (9). Both the epileptogenic lesion and zone should be delineated before surgery for cessation of seizures. The epileptogenic zone can be located anywhere around the margin of, and even distant from, a lesion (1, 2, 10). Conventional noninvasive scalp video-EEG recordings are not adequate to define the epileptogenic zone because it requires an area of brain tissue at least 6 cm square to generate activity of sufficient magnitude to be seen on scalp-recorded EEGs (11).

Compared with electrical fields, magnetic fields are unaffected by inhomogeneous shell elements, making computations of source localization more straightforward; several studies have documented the accuracy of the resulting source localization for SEF (8) and interictal epileptic spikes (3, 4, 6, 7, 12). From our results, MEG spikes adjacent to a lesion were highly correlated to the intraoperative ECoG interictal spike zone. If the preoperative information provided by MEG about the relationship between the lesion and the epileptic irritative zone that includes the epileptogenic zone is accurate, an ECoG-guided surgical approach would be less invasive than procedures that seek irritative spikes on ECoG without prior knowledge of the sources.

The successful outcomes of seizure surgery in lesional epilepsy reported here, in which MEG-spike sources correlated with ECoG spikes and surgical sites, support further the concept that clusters of MEG spikes predict the epileptogenic zone within the irritative zone around the lesion. The additional cortical excision or MST is recommended to remove or disconnect the epileptogenic zone when predicted by MEG.

5 Conclusion

In children with ExHLE, magnetic source imaging (MSI) can non-invasively delineate lesion, epileptic zone and eloquent cortex. MSI and intraoperative navigation system, therefore, provide asymmetrical epileptogenecity adjacent to the lesion, complete excision of the lesion, and minimal functional deficits in pediatric lesional epilepsy.



A)

B)

Figure 1: *A 13-year-old right-handed girl had a 10-year history of simple partial, secondarily generalized seizures. Clusters of MEG-spike sources (white open triangles projected on to the nearest slices) were found anterior and lateral to a frontoparietal tumor. Note that the sagittal slice included, but not the axial slice, cut through the tumor, making the sources appear within the tumor (A). For this patient, SEF was also localized (solid black squares) for stimulation of the left lower lip (LLL) and left-hand second digit (LD2). There was also a cluster of spikes in left-central region (mirror focus) where no ictal onsets were recorded during prolonged video-EEG monitoring (B).*

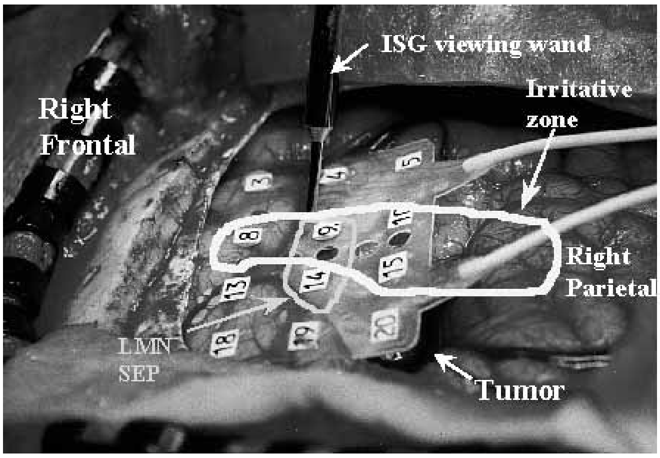


Figure 2: *After lesionectomy, intraoperative ECoG with a viewing wand showed residual interictal spike discharges on electrodes #8, #9, #10 (yellow circles), and sensory cortex on #9 and #14 by stimulation of the left median nerve (white circles). Subsequently, further subcortical excision was performed. She has been seizure-free on carbamazepine for 45 months after the surgery.*

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